2006 R&D 100 AWARDS ENTRY FORM

1 Submitting Organization

Organization	Ernest Orlando Lawrence Berkeley National Laboratory (LBNL)
Address	1 Cyclotron Road
City, State, Zip	Berkeley, CA 94720-8125
Country	USA
Submitter	Pamela Seidenman
Phone	510/486-6461
Fax	510/486-6457
E-mail	PSSeidenman@lbl.gov

AFFIRMATION: I affirm that all information submitted as a part of, or supplemental to, this entry is a fair and accurate representation of this product.

Submitter's signature: ____________________________________

2 Joint entry with:

Organization	Institute of Paper Science and Technology at Georgia Tech
Address	500 10th Street, NW
City, State, Zip	Atlanta, GA 30332-0620
Country	USA
Contact Name	Emmanuel Lafond
Phone	404 894-3707
Fax	404 894-4778
E-mail	emmanuel.lafond@ipst.gatech.edu

3 Product name:

Laser Ultrasonic Sensor (LUS)

4 Briefly describe (25 words or less) what the entry is (e.g. balance, camera, nuclear assay, etc.)

A Laser Ultrasonic Sensor for nondestructive, non-contact, quantitative, on-line measurements of mechanical properties of sheet materials such as paper, polymers or metals at production speeds.

5 When was this product first marketed or available for order? (Must have been first available in 2005.)

2005

6 Inventor or Principal Developer (List all developers from all companies)

Developer Name	Paul Ridgway
Position	Staff Research Associate
Organization	Ernest Orlando Lawrence Berkeley National Laboratory
Address	1 Cyclotron Road
City, State, Zip	Berkeley, CA 94720
Country	USA
Phone	(510)486-7363
Fax	(510)486-7303
E-mail	PLRidgway@lbl.gov

Developer Name	Richard Russo
Position	Staff Scientist
Organization	Ernest Orlando Lawrence Berkeley National Laboratory
Address	1 Cyclotron Road
City, State, Zip	Berkeley, CA 94720
Country	USA
Phone	(510)486-4258
Fax	(510)486-7303
E-mail	RERusso@lbl.gov

Developer Name	Emmanuael Lafond
Position	Research Scientist II
Organization	Institute of Paper Science and Technology at Georgia Institute of Technology
Address	500 10th St. N.W.
City, State, Zip	Atlanta, GA 30332-0620
Country	USA
Phone	(404)894-3707
Fax	
E-mail	emmanuel.lafond@ipst.gatech.edu

Developer Name	Ted Jackson
Position	Engineer
Organization	Institute of Paper Science and Technology
Address	500 10th St.N.W.
City, State, Zip	Atlanta, GA 30332-0620
Country	USA
Phone	(404)894-3707
Fax	
E-mail	ted.jackson@ipst.gatech.edu

Developer Name	Chuck Habeger
Position	Scientist Advisor
Organization	Weyerhaeuser Technical Center
Address	P.O. Box 9777
City, State, Zip	Federal Way, WA 98063-9777
Country	USA
Phone	(253) 924-6951
Fax	
E-mail	Chuck.Habeger@weyerhaeuser.com

7 Product price

To be negotiated with licensee.

8 Do you hold any patents or patents pending on this product?

Yes. U.S. Patent No. 6,356,846, entitled "System and method of reducing motion-induced noise in the optical detection of an ultrasound signal in a moving body of material," issued on March 12, 2002.

9 Describe your product's primary function as clearly as possible. What does it do? How does it do it? What theories, if any, are involved?

The Laser Ultrasonic Sensor (LUS), an innovative sensor that features state-of-the-art laser ultrasonic technology, promises to dramatically streamline the way paper is manufactured. If it is widely implemented, the LUS will significantly reduce the consumption of trees and chemicals and save the U.S. paper industry approximately \$220 million in energy costs and \$330 million in fiber costs each year.

The LUS is the first commercial application of laser ultrasonics to the measurement of the elastic properties paper. It measures a paper's bending stiffness and shear stiffness—two hallmarks of paper quality—as the paper is manufactured at high speeds in a papermaking machine. No other technology enables the non-contact measurement of these qualities during the paper manufacturing process.

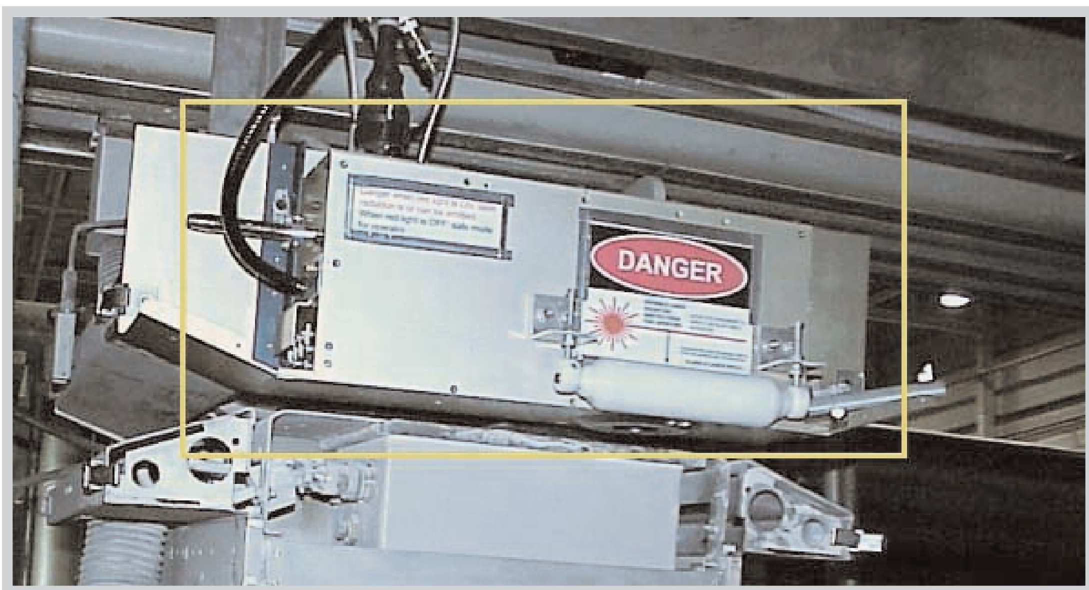

Figure 1 The LUS installed on a scanning platform on one of Boise Paper's paper manufacturing machines

This breakthrough technology is important because while everyone uses paper, few people realize how much energy and money, and how many natural resources, are consumed by the U.S. pulp and paper industry to manufacture paper. Paper manufacturing in the U.S. is a \$150 billion industry and is the third largest consumer of energy in the nation. Each year, timber harvested to produce the 100 million tons of paper made in the U.S. amounts to a ribbon of wood that, if stacked four feet wide by four feet high, would stretch from coast to coast 15 times.

In order to make this energy and resource-intensive industry more efficient, the U.S. Department of Energy's Office of Industrial Technologies funded the LUS as part of a program to reduce the energy consumption of several industries.

The 2,000-year-old craft of papermaking is an obvious candidate for improvement. For decades, the bending stiffness of paper has been assessed via a slow, inefficient process: After a 15 to 40-ton paper roll is manufactured, a few samples are carefully obtained from the end of the roll and analyzed for their mechanical properties. If the samples don't meet certain specifications, the entire roll is recycled into pulp or sold as an inferior grade. To avoid this costly mistake, manufacturers often use more pulp than necessary to ensure the final product isn't substandard. Not only does this consume more raw materials than necessary, it consumes more energy: the more pulp used per unit of paper, the more heat is required during the drying phase, which even in the most efficient mills requires an enormous amount of energy.

Much of this waste could be avoided if the paper’s quality is evaluated during the manufacturing process, instead of afterwards. With this in mind, the Berkeley Lab and IPST team pioneered a sensor that tracks papers’ bending stiffness on the fly, in real time. Their sensor employs a cutting edge technology called laser ultrasonics, in which acoustic waves are generated with a pulsed laser in a material to determine one or more of its physical properties. These acoustic waves are monitored with a laser-based detector without touching the sample.

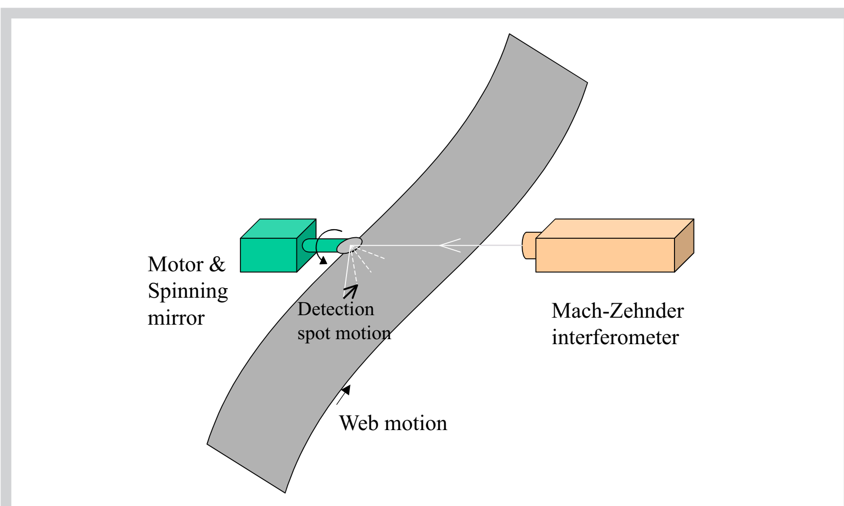

Figure 2 Laser ultrasonic detection on moving materials

In the LUS, one laser is used to generate an ultrasonic disturbance by localized heating in the paper while it is traveling at high speeds through a papermaking machine at a mill. A second laser is used in an optical interferometer that detects the mechanical ultrasonic waves generated in the sheet by the first laser. The velocity at which the ultrasound waves travel from the excitation point through the paper to the detection point is related to two elastic properties of importance in paper and other sheet materials: flexural rigidity (or bending stiffness) and out-of-plane shear rigidity.

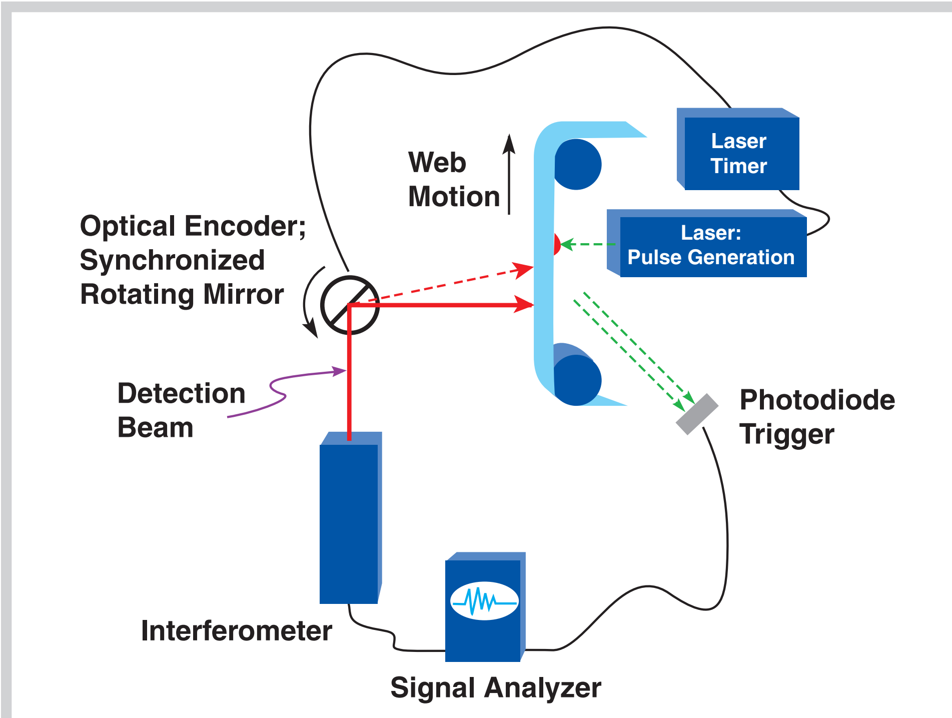

Figure 3 Principles of LUS operation

In the mechanical operation of the sensor, a detection beam from a commercially available interferometer is directed toward a quickly rotating mirror. As the mirror spins, the beam is reflected in a circular pattern much like a lighthouse beam. An optical encoder determines when the detection beam is perpendicular to the paper, at which time an adjustable delay circuit fires the pulsed neodymium-yttrium-aluminum-garnet laser. This nanosecond pulse causes a microscopic thermal expansion or ablation on the paper, which is too small to mar the paper and effect how it absorbs ink, but strong enough to send ultrasonic shock waves through the sheet. The waves propagate through the paper until they're detected by the interferometer. Because the laser is synchronized to only fire when the detection beam is perpendicular to the paper, the distance between the ablation point and detection point is known, and the waves' speed is calculated.

Software developed as a part of this project analyzes the signals in real-time to measure the flexural rigidity in lightweight papers, and the flexural rigidity and shear rigidity in heavier paperboard grades. Flexural rigidity is a property that determines end-product rigidity and is of great importance to a wide variety of paper grades. Shear rigidity is important in packaging grades because it strongly influences downstream operations such as fluting, scoring, creasing and bending.

A significant advantage of the LUS is that it does not require any contact with the paper, thereby avoiding possible breaks or the inadvertent creation of paper defects. This is important because the papermaking machines move the sheet at speeds up to 30 meters per second (60 miles per hour) and the slightest contact could break the sheet, cause costly machine downtime, and mar lightweight grades such as copy paper and newsprint.

In addition, a groundbreaking feature of the LUS is that it enables the integration of feedback process controls based on real time measurements of the bending stiffness of the sheet, meaning the LUS measurements can be fed back into the paper machine's process control computers in real time. These computers can therefore continuously adjust process variables to keep bending stiffness adequate while minimizing use of fiber feedstock. This results in savings of energy, chemicals and natural resources because of reduced production of off-specification product.

This technology has applications to all sheet manufactured materials including nonwovens, plastic film, sheet metal and glass.

The LUS has been field-tested at a paper mill in Jackson, Alabama, owned by Boise Paper—the latest in a string of successful real-world tests. The two-week test, con-

Figure 4 Successful trial at Boise Paper paper mill in Jackson, AL

ducted in February 2005, demonstrated that the LUS can perform in the demanding and nonstop environment of a working paper mill, in which sheet speeds approach 25 meters per second. This mill produces one 40-ton reel of copy paper measuring 30 feet wide and 33 miles long every 47 minutes.

In 2003, Berkeley Lab and IPST engineers also conducted a successful pilot-scale test of the LUS at Mead Paper Company's research center in Chillicothe, Ohio. Emmanuel Lafond, lead scientist for IPST at Georgia Tech said, "We have cleared another hurdle toward commercialization of a technology that has the potential to save a significant amount of raw materials and energy while producing the same surface area of paper."

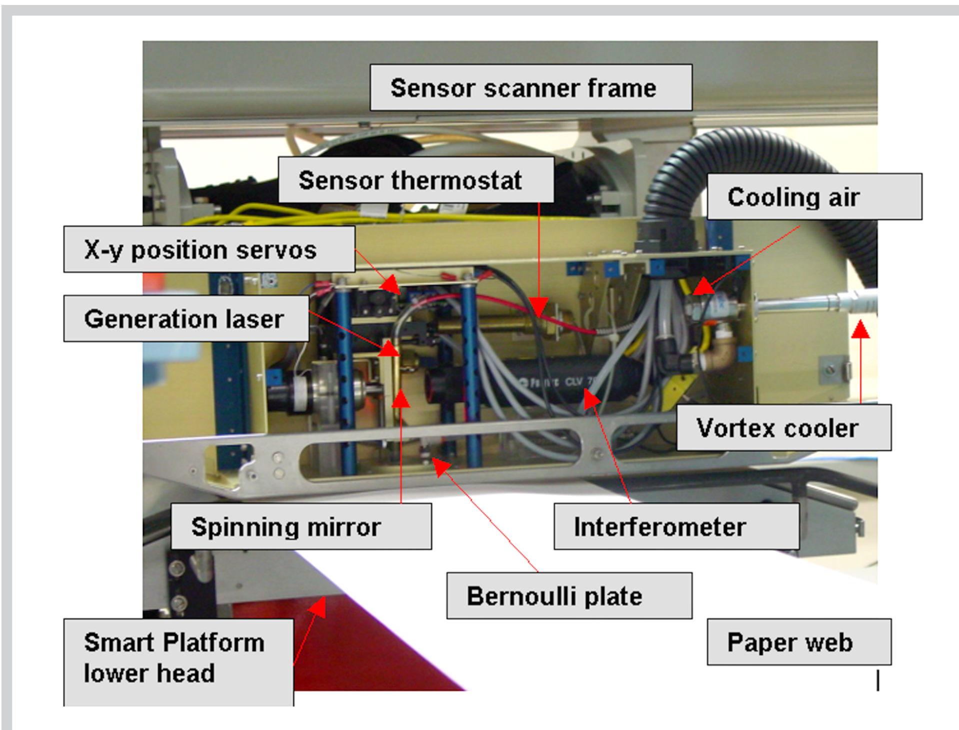

Figure 5 Sensor with cover removed

The LUS is designed to be easily mounted on an ABB Smart Platform Scanner, which is commonly used in paper mills. The weight of the on-machine detector is only 15 pounds. It contains the spinning mirror that rotates synchronously with the speed of the paper sheet, the servos that change the distance and direction of the measurements, and the interferometer. The excitation laser, interferometer controller and associated electronics are located in a nearby control room and are connected to the on-machine detector by fiber optic and electrical cables.

The LUS can be installed on the ABB Smart Platform in a matter of hours with a removal time of about one hour. After the initial installation, mounting and removal of the detector from the ABB scanning head package takes only several minutes.

Figure 6 LUS mounted "piggy back" on the head package of an ABB Smart Platform

10A. List your product's competitors by manufacturer, brand name and model number.

There are no other online sensors for measuring paper stiffness. Therefore, there is no competitive technology or other devices that offer this measurement on the papermaking machine. Instead, all current measurements of bending stiffness are accomplished in a laboratory on stationary paper samples that are cut from the paper roll after it is manufactured. Furthermore, there are no simple laboratory measurements of out-of-plane shear rigidity. Laboratory instruments that are typically used to measure bending stiffness on paper samples include:

Lorentzen & Wettre, L&W Bending Resistance Tester

Gurley Precision Instruments, Gurley Stiffness Tester, model 4171DS1N

Taber Industries, Taber Stiffness Tester, model 150-E

10B. Supply a matrix or table showing how the key features of your product compare to existing products or technologies. Include both numerical and descriptive comparisons.

Product Feature	LBNL/IPST Laser Ultrasonic Sensor	L&W Bending Resistance Tester	Gurley Stiffness Tester	Taber Stiffness Tester	Competitive Advantage
Energy savings	Yes—over 38 million KWt saved per mill	No	No	No	Energy savings could exceed $220 million per year across the U.S.
Timber savings	Yes—a single mill might use 110,000 fewer trees each year to produce the same amount of paper	No	No	No	Over 34 million fewer trees would be cut down each year, while producing the same amount of paper per year
Reduces waste?	Yes—reduces production of off-spec product that must be recycled. Reduces industrial waste generation. In a typical mill, one less 40-ton roll would need to be recycled every 3.2 days	No	No	No	Real-time measurements and feedback process control would result in 114 fewer 40-ton roles being recycled each year
Paper motion	Moving to >30m/s, or Static	Static only	Static only	Static only	Allows continuous feedback process control
Contact/ noncontact	Non contact	Contact-Samples must be cut out of paper web for testing[1]	Contact-Samples must be cut out of paper web for testing[1]	Contact-Samples must be cut out of paper web for testing[1]	There is no damage to the paper tested. Paper can be sent to customer
Real-time measurement while on paper making machine?	Yes	No (samples must be equilibrated off line in a testing lab)	No (samples must be equilibrated off line in a testing lab)	No (samples must be equilibrated off line in a testing lab)	Allows real time manufacturing adjustments via feedback process control.

Product Feature	LBNL/IPST Laser Ultrasonic Sensor	L&W Bending Resistance Tester	Gurley Stiffness Tester	Taber Stiffness Tester	Competitive Advantage
Can install on papermaking machine (online)?	Yes	No (destructive test)	No (destructive test)	No (destructive test)	Allows real-time measurements and feedback process control for stiffness
Measurements/ role of paper	High (Many thousands of measurements per 40-ton roll)	Low (3-5 per 40-ton roll)	Low (3-5 per 40-ton roll)	Low (3-5 per 40-ton roll)	Far more complete inspection of product
Cost per measurement?	Low ($0.0035, or 0.35 cents)[2] No significant labor cost involved	High ($0.14, or 14 cents, not including significant labor cost (several minutes per measurement)[3]	High ($0.04, or 4 cents, not including significant labor cost (several minutes per measurement)[3]	High ($0.07, or 07 cents, not including significant labor cost (several minutes per measurement)[3]	No significant operator labor cost, less expensive by at least one order of magnitude
Instrument/ Sensor Cost	Approx. $200,000	$24,000	$6,300	$12,000	LUS cost pays for itself within a few months.
Sample preparation and handling?	Not necessary	Yes, operator handling skill affect measurements	Yes, operator handling skill affect measurements	Yes, operator handling skill affect measurements	Reduced operator labor cost, no effect of sampling and handling technique on measurement
Measurement is scientifically defined	Yes	No (Test configuration is not a pure bending mode)	No (Test configuration is not a pure bending mode)	No (Test configuration is not a pure bending mode)	Can use theory to calculate measurement specifications for desired product performance

[1]Instead of laser ultrasonics, all competing products employ a two-point clamp and bending process. Although each product differs, in all cases a carefully prepared paper sample, free of creases, wrinkles and curvature, is cut to precise dimensions and is clamped at one end in the instrument.

[2]Assumes 2.8s/measurement, 24 hours/day, 365 days/yr for 5 years, and instrument cost of $200K. 2.8s is the current measurement period. The measurement rate could be increased ten-fold if desired.

[3]Assumes 3 measurements per roll, 47min/roll, 24 hours/day, 365 days/yr for 5 years, and instrument cost indicated in the following row in the table. Labor costs would significantly increase these estimates.

10C. Describe how your product improves upon competitive products or technologies.

Unlike all other commercial products, the Laser Ultrasonic Sensor offers on-line, non-contact, real-time measurements of two fundamental material properties of paper: flexural rigidity, also known as bending stiffness, and shear rigidity. Accordingly, the LUS offers the following advantages over other commercial products:

Energy savings: About 75 percent of the paper produced in the U.S. is appropriate to LUS-based process monitoring, and there are 204 integrated mills in the U.S. that could achieve energy savings from the LUS. The total annual U.S. energy savings if all of these mills adopted the LUS would be 7,752 million kWhr/year or approximately 8TeraWhr/year. This equates to $1.08 million in energy savings per mill per year. If all 204 mills adopted the LUS, the total annual U.S. energy savings would be $220 million per year. The total annual electricity consumption of the sensor itself is estimated to be less than 9,000 kWh, which is 0.02% of energy saved.

Fewer trees cut down: In a typical mill, such as the one in which the LUS trial took place, one 40-ton roll of copy paper is produced every 47 minutes, and 31 such rolls are produced each day. Previous to the LUS, a substandard test value meant the entire roll must be recycled or sold at a lower price. Very conservative estimates indicate that in a mill equipped with the LUS, there would be one less 40-ton roll that would need to be recycled about every 3.2 days. Based on the assumption that one ton of uncoated virgin (non-recycled) printing and office paper uses 24 trees, the mill would require roughly 110,000 fewer trees each year thanks to the LUS. If the LUS was adopted in the production of all appropriate paper grades (75% of total production), more than 34 million trees would be saved each year.

Return on investment: Although the initial price of the LUS is estimated to be around $200,000, it should pay for itself in less than two months. Calculations have been made using the IPST Jaakko Poyry Economic Model* for a paper machine producing 175,000 metric tons of uncoated free sheet per year. Based on fiber, chemical and energy savings from a 2% reduction in basis weight, combined with a 1% increase in production from less off-spec material, the calculations reveal that, conservatively, a mill could save about $1.4 million annually by using the LUS.

Resource savings: Because the LUS will ensure that paper mills are using the optimum amount of fiber during the production process, the LUS will save $1.6 million in fiber costs per mill per year. If all 204 mills adopted the LUS, the total U.S. cost savings in fiber will be $326 million per year.

On-line measurements: No other commercial instrument can measure these two properties on the paper machine at production speeds. The LUS can also be used off-line in a lab, allowing verification of online system measurements.

Non-contact: The LUS conducts its measurements without touching the paper, an important advantage given that the paper moves at speeds up to 20 meters per second (45 miles per hour) and the slightest contact could break the sheet and cause costly machine downtime, or mar lightweight grades.

Thousands of measurements per paper roll: The LUS can take thousands of measurements continuously per 40-ton roll of paper, while all other commercially available methods offer a limited number of measurements taken only at the end of the 40-ton roll. Therefore, the LUS offers a vastly more comprehensive inspection of the product.

Enables real-time feedback process control: The LUS includes algorithms that provide automated adjustment of the stiffness measurement for basis weight, moisture and temperature variations in the paper sheet. The on-machine stiffness measurements will enable automatic or manual process control such that product uniformity can be improved during the manufacturing process, waste from off-spec product can be reduced, and energy consumption can be decreased. This will result in a much more cost, energy, and resource efficient papermaking process.

Minimal labor costs: Once the LUS is installed (which only requires a matter of hours if done on a current ABB platform), the labor cost of each measurement is negligible. All other commercially available sensors are off-machine laboratory instruments that require samples to be carefully prepared and handled, incurring much higher labor costs. In addition, because the competing products only allow postproduction testing of the paper, massive paper rolls found to be under specifications will incur significant labor costs.

Minimal maintenance needs: The yearly maintenance (change flash lamp of generation laser once per month during a machine shutdown) and labor (inspection, cleaning, and change of minor parts) costs are estimated to total no more than $7000.

11A. Describe the principal applications of this product.

The LUS is specifically designed to allow optimization of paper quality while reducing fiber use, thus saving the paper industry millions of dollars in energy and raw material costs during the paper manufacturing process. Concomitantly, it will help conserve millions of trees and tons chemicals annually used to make paper.

11B. List all other applications for which your product can now be used.

This technology has applications to all sheet manufactured materials including paper, nonwovens, plastic film, sheet metal and glass. Measurable properties include all of those that affect the speed of propagation of plate waves in a material, such as elasticity (bending, shear, tensile, and compressive stiffness in the three dimensions), thickness, density, temperature, and possibly roughness.

The value of this technology is the opportunity it gives for real time feedback control of the manufacturing process, thereby producing a product that meets specifications while saving energy and natural resources from reduced production of off-specification product (and possible reprocessing costs), and reduced utilization of feedstock to produce in-specification product.

12. Summary. State in layman's terms why you feel your product should receive an R&D 100 Award. Why is it important to have this product? What benefits will it provide?

The LUS is unprecedented in its ability to measure two important aspects of paper quality (bending stiffness and shear rigidity) on moving sheets at high speeds without contact. It also inspects the product more comprehensively than other methods. Because these paper properties cannot currently be measured on a paper machine, today's paper machines are essentially running "out of control" as far as these mechanical properties are concerned.

The ability to make these measurements will result in vastly improved process control, and decreased raw material use, energy costs, and labor costs. If all U. S. paper mills were to adopt the Laser Ultrasonic Sensor, not only would their capital costs be recouped within months, but 34 million trees, 8 Terawatt-hr of energy, and $550 million could be saved each year. No other currently available technology comes close to offering these extremely valuable measurements to the paper manufacturing industry.

ORGANIZATION DATA

13 Contact person to handle all arrangements on exhibits, banquet, and publicity.

Name	Pamela Seidenman
Position	Marketing Manager, Technology Transfer
Organization	Ernest Orlando Lawrence Berkeley National Laboratory (LBNL)
Address	1 Cyclotron Road, 90R1070
City	Berkeley
State	CA
Zip/Postal	94720-8125
Country	USA
Phone	510/486-6461
Fax	510/486-6457
E-mail	PSSeidenman@lbl.gov

Appendix
List of Attachments
2006 R&D 100 Awards
ENTRY—Laser Ultrasonic Senor (LUS)

A. Letters of Support

- Kevin Rucker, Boise Paper
- Bruno Mulder, StoraEnso Berghuizer Mill
- Jeff Harris, Northwest Energy Efficiency Alliance

B. Media Coverage and Popular Articles

- List
- Selected Examples

C. Publications

- Ridgway, P.L., Russo, R.E., Lafond, E., Jackson, T., Habeger, C., "Laser Ultrasonic System for On-Line Measurement of Elastic Properties of Paper," *Journal of Pulp and Paper Science*, 29 (9) 289-293 (2003)

  This paper has won two awards:
  2003—Technical Association of the Pulp and Paper Industry Outstanding Research Paper Award
  2004—Johannes A. Van Den Akker Prize for Paper Physics

- Ridgway, P., Hunt, A., Quinby-Hunt, M., and Russo, R., "Laser Ultrasonics on Moving Paper," *Ultrasonics* 37:395-403 (1999), LBNL-43615

D. Fact Sheet

- http://www.ipst.edu/tech_transfer/pdfs/051129_fact_sheet_luss.pdf

E. Movie

- "Laser Ultrasonic Stiffness Sensor" Prepared May 2004, prior to completion of testing. (Seven minutes)

2006 R&D 100 Awards
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Appendix A

Letters of Support

- Kevin Rucker, Boise Paper
- Bruno Mulder, StoraEnso Berghuizer Mill
- Jeff Harris, Northwest Energy Efficiency Alliance

2006 R&D 100 Awards
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Appendix B

Media Coverage and Popular Articles

- List
- Selected Examples

A sampling of Media Coverage

Laser ultrasonics technology closes in on commercialization
http://www.tappi.org/index.asp?pid=33835&ch=1&bhcd2=1136853998
TAPPI.org, December 2005

Laser Ultrasonics Technology Passes Major Milestone Towards Commercialization
http://www.paperage.com/issues/sept_oct2005/09_2005ofinterest.html
PaperAge, September/Oct 2005

New paper-making sensor could save energy, money
http://www.nwcurrent.com/efficiency/industrial/1802672.html
NWCurrent.com, September 2005

Laser Ultrasonics Technology Passes Major Milestone Towards Commercialization
http://newsmanager.commpartners.com/tappiaotc/issues/2005-07-13.html
TAPPI Ahead of the Curve, July 2005

Laser Ultrasound Sensor Tested in Paper Mill
http://www.photonics.com/spectra/tech/read.asp?techid=1708
Photonics Technology World, July 2005

New Paper-Making Sensor Could Save Millions in Energy, Raw Materials
http://www.greenbiz.com/news/news_third.cfm?NewsID=28234
Greenbiz.com, June 2005

Energy-Saving Paper Sensor Passes Major Milestone
http://www.physorg.com/news4221.html
Physorg.com, May 2005

Streamlined Paper-making
http://www.memagazine.org/backissues/june02/departments/tech_focus/techfocus2.html
Mechanical Engineering, June 2002

Laser Ultrasound Evaluates Paper
http://www.photonics.com/spectra/tech/XQ/ASP/techid.1381/QX/read.htm
Photonics Technology World, June 2002

Laser ultrasonics tests paper quality
http://optics.org/articles/news/8/3/7/1
Optics.org, March 2002

Laser Beam to Reduce Costs of Paper Manufacture
http://www.dailycal.org/article.php?id=8011
Daily Cal, March 2002

Sensor streamlines paper making
http://www.hindu.com/thehindu/seta/2002/03/21/stories/2002032100030300.htm
The Hindu, March 2002

Berkeley Lab and IPST Press Releases

Energy-Saving Paper Sensor Passes Major Milestone
http://www.lbl.gov/Science-Articles/Archive/EETD-paper-sensor.html
May 2005

Laser Ultrasonics Technology Passes Major Milestone Towards Commercialization
http://www.ipst.gatech.edu/news/current/050708_laser_ultrasonics.html
May 2005

Laser Ultrasonic Sensor Streamlines Papermaking Process
http://www.lbl.gov/Science-Articles/Archive/EETD-papersensor-Ridgway.html
February 2002

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Appendix C

Publications

- Ridgway, P.L., Russo, R.E., Lafond, E., Jackson, T., Habeger, C., "Laser Ultrasonic System for On-Line Measurement of Elastic Properties of Paper," *Journal of Pulp and Paper Science*, 29 (9) 289-293 (2003)

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- Ridgway, P.L., Russo, R.E., Lafond, E., Jackson, T., Habeger, C., "Laser Ultrasonic System for On-Line Measurement of Elastic Properties of Paper," *Journal of Pulp and Paper Science*, 29 (9) 289-293 (2003)

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Appendix D

Fact Sheet

- http://www.ipst.edu/tech_transfer/pdfs/051129_fact_sheet_luss.pdf

2006 R&D 100 Awards
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Appendix E

Movie

- “Laser Ultrasonic Stiffness Sensor” Prepared May 2004, prior to completion of testing. (Seven minutes)